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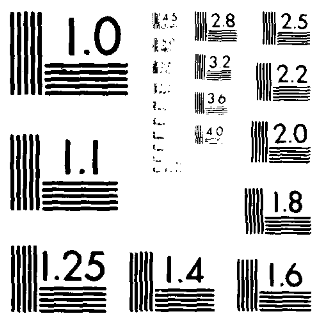
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Research and Development Technical Report

ERADCOM-78-C-3008-1

AN/TPQ-37 TRANSMITTER TUBE IMPROVEMENTS

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APRIL 1979

FIRST INTERIM REPORT FOR PERIOD SEPTEMBER 1978 THRU MARCH 1979

DISTRIBUTION STATEMENT

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Prepared for:

ERADCOM

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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (18) ERADCOM (19) 78-C-3008-1	2. GOVT ACCESSION NO. (9) Interim rept. no. 1, 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) AN/TPQ-37 TRANSMITTER TUBE IMPROVEMENTS.	5. TYPE OF REPORT & PERIOD COVERED ~~First Interim Report for~~ 28 Sep 1978 - 28 Mar 1979
	6. PERFORMING ORG. REPORT NUMBER (14) EDD-W-08140-1
7. AUTHOR(s) (10) S. L. BOSMA	8. CONTRACT OR GRANT NUMBER(s) (15) DAAB07-78-C-3008 /
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hughes Aircraft Company Electron Dynamics Division 3100 West Lomita Boulevard Torrance, CA 90509	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS CT-8-08754-CT-CA/01
11. CONTROLLING OFFICE NAME AND ADDRESS W15P87 US Army ERADCOM ATTN: ET&D LAB, DELET-BM, FT. Monmouth, NJ 07703	12. REPORT DATE (11) 27 April 1979 / 13. NUMBER OF PAGES 22
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (12) 27	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Traveling Wave Tube (TWT)	PPM Focusing	Output VSWR
High Power	Samarium Cobalt	Reliability
Grid Pulsed	Isolated Anode	
Osmium-Ruthenium coated cathode	Gain Variations	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this program is to improve the performance and reliability of the AN/TPQ-37 transmitter tube. The task is to build and test two high power, PPM focused, grid pulsed Traveling Wave Tubes (TWT) that meet the requirements of Technical Guidelines MW-119B.

The TWT will employ a M-type cathode for reduced temperature operation and extended life. Gain variations will be minimized by use of in-band loss techniques and weight will be reduced by using samarium cobalt magnets.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 BACKGROUND

The prototype transmitter program began in 1973. Hughes EDD was contracted to build the 1715H TWT as the output RF amplifier for the transmitter. A total of four TWTs were built and delivered as advanced development models. The first 1715H was tested to Quality Conformance Inspection (QCI)-Part 1 and shipped in June of 1974. The second tube was tested to QCI-Parts 1 and 2 without any deviation. QCI-Part 3 testing has been performed on an AN/TPQ-37 transmitter including a 1715H TWT. This tube design has demonstrated every performanc requirement of the system.

Hughes EDD has delivered four production model 1715Hs. The subsequent production tubes for the AN/TPQ-37 transmitter will have an isolated anode incorporated in the electron gun and as such will be designated as the 1743H TWT.

The Hughes 1743H is a high-power, S-band traveling-wave tube. It utilizes the coupled cavity interaction circuit with an integral periodic permanent magnet focusing structure. The circuit is severed into three separate cascaded sections to provided high gain. The circuit pole pieces are directly liquid cooled so that high average power can be obtained in this compact PPM focused package. Beam modulation is provided by a shadow grid electron gun.

Two model 1743H tubes have been built and delivered for the AN/TPQ-37 artillery locating radar. The complete mechanical and electrical designs were established during the development phase; the tube is currently in full production. The tube uses a type N coaxial input connector and WR 284 waveguide output window. It weighs 180 pounds. It is liquid cooled using an ethylene glycol and water mixture.

2.0 ISOLATED ANODE ELECTRON GUN

The four major components of the isolated anode electron gun are shown in Figure 2-1. The inner gun is at high voltage and is isolated from the anode by the cathode to anode insulator. In an ordinary electron gun the anode is grounded to the TWT input pole piece, but in this case the anode is isolated from ground potential by the anode insulator. The spacing between the anode and pole piece must be capable of withstanding full cathode voltage potential as must the anode insulator. The incorporation of an isolated anode electron gun involves only mechanical redesign. No electrical or beam optics changes are necessary. No modification of magnetic field entrance conditions, which would effect focusing, is required. A picture of a complete isolated anode gun as used on the 1743H is shown in Figure 2-2.

The advantage of an isolated anode electron gun is that it eliminates the need for a crowbar to protect the TWT by greatly reducing the current during a gun arc. Figure 2-3 illustrates the current limiting concept. The anode is connected to ground through a high voltage glowbar resistor. With the onset of an inner gun to anode arc, the anode potential instantaneously drops towards the cathode potential as a result of the arc current flowing through the anode resistor. By using a 2000 Ω resistor, the arc current is limited to 22 amperes which is two orders of magnitude less current than without the resistor. This low current will not damage the anode surface and therefore the requirement for a crowbar is eliminated. Tests in the AN/TPQ-37 transmitter using a 1743H have successfully demonstrated this concept and the future transmitter build standard will not have a crowbar.

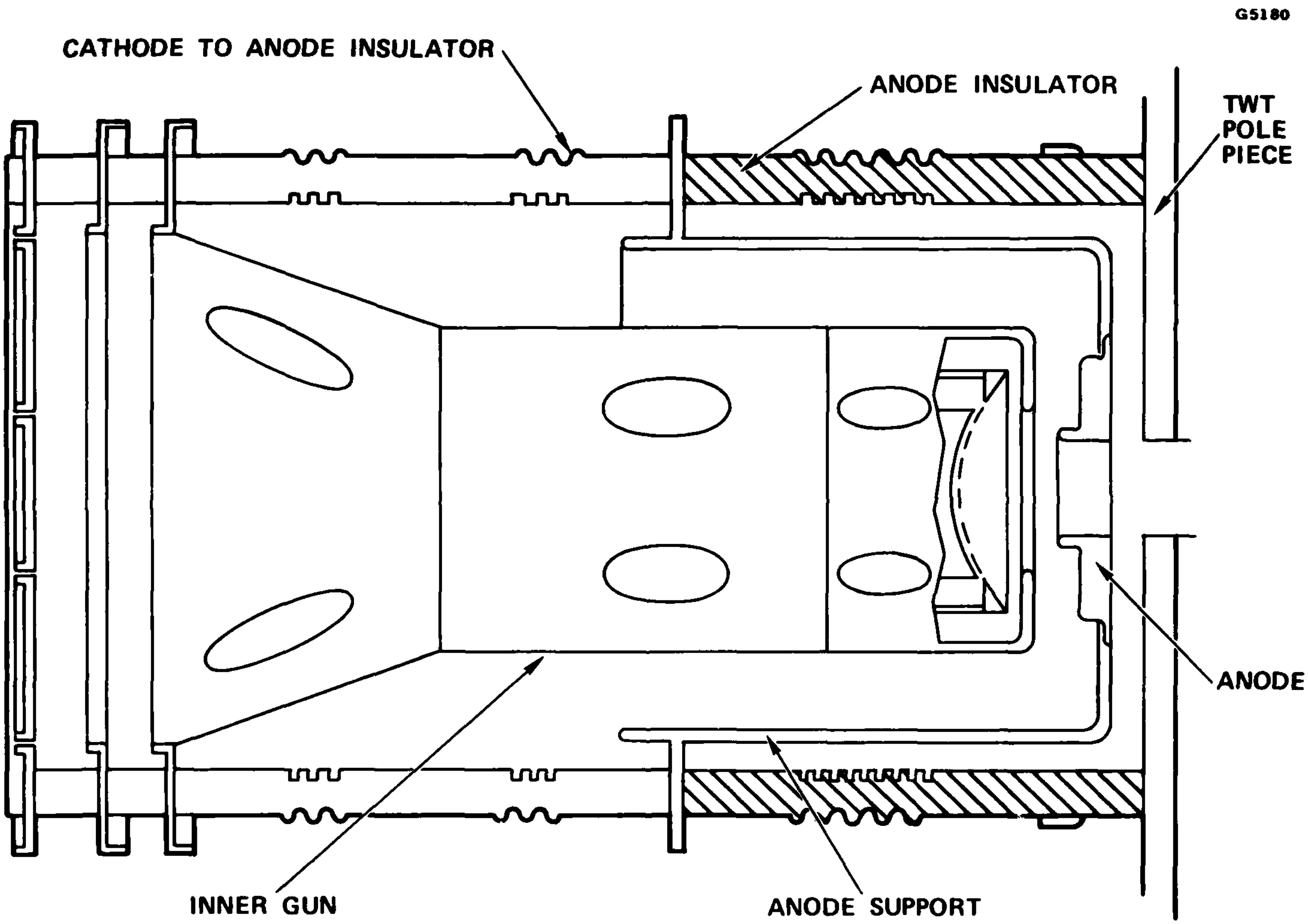

Figure 2-1 Sectioned view of isolated anode electron gun.

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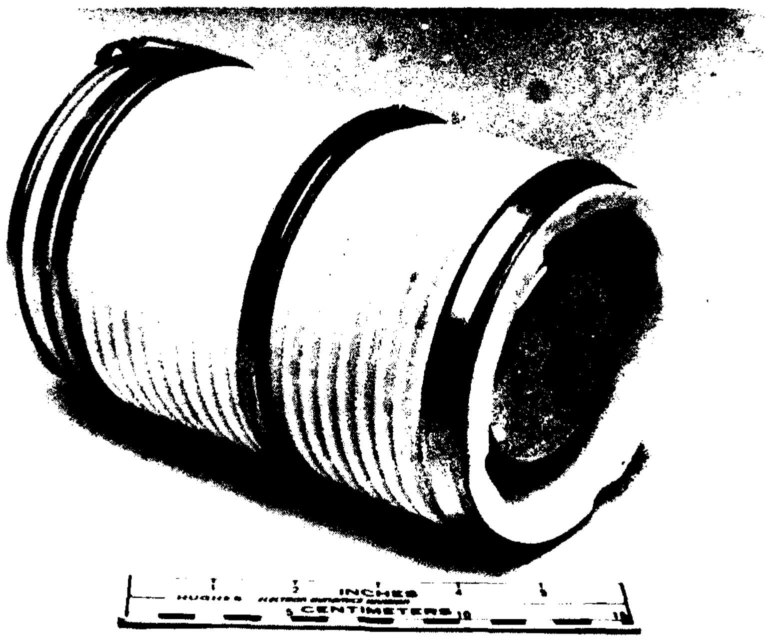

Figure 2-2   Isolated anode electron gun.

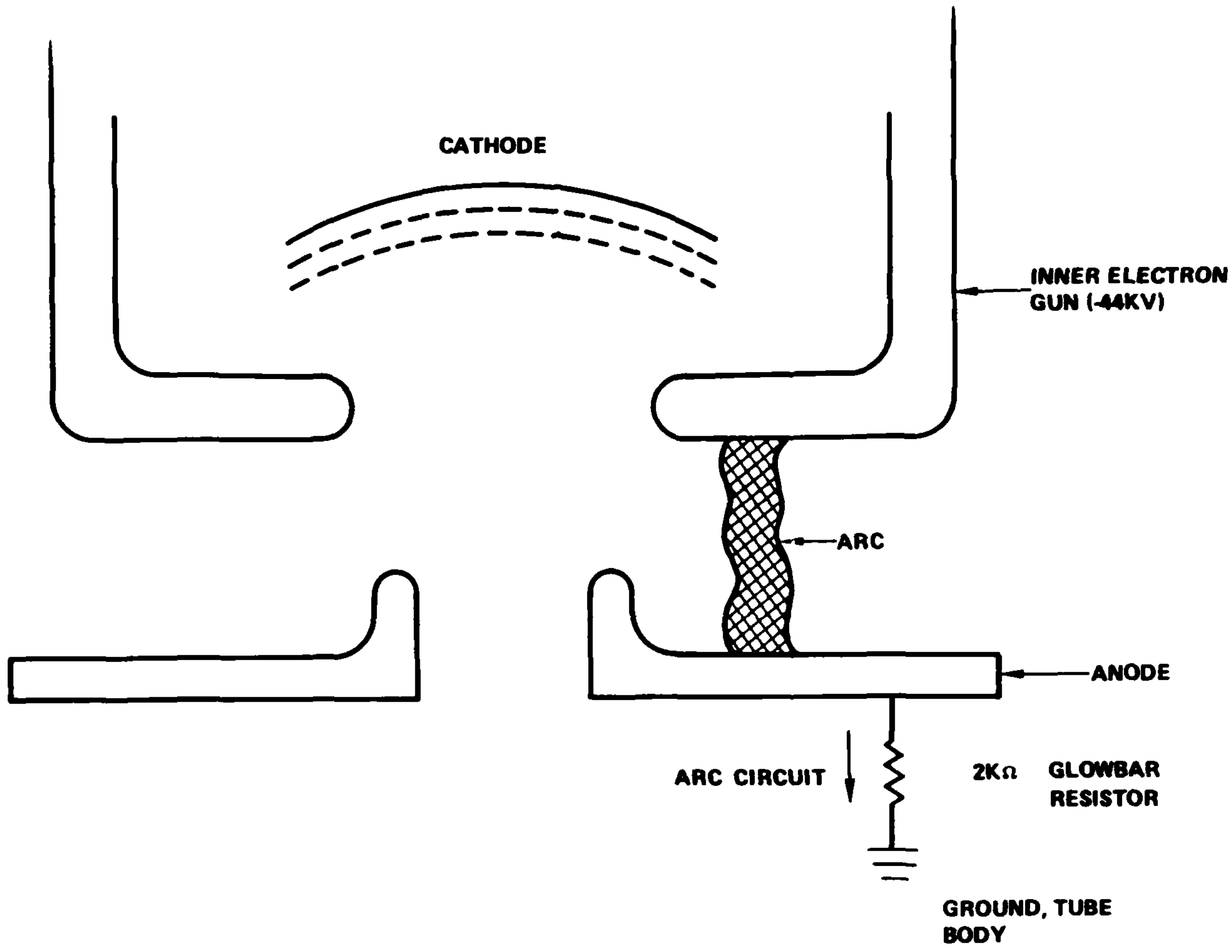

Figure 2-3   Arc current limiting concept, isolated anode electron gun.

3.0 1757H TRAVELING WAVE TUBE DESIGN

3.1 DESIGN SUMMARY

The baseline design for the proposed tube will be the existing Hughes 1743H TWT which meets all the performance and outline specifications of the AN/TPQ-37 transmitter. The design changes to this baseline are listed below:

1. Electron Gun - Hughes will incorporate the isolated anode, shadow grid electron gun (model 120 CGB) which was developed for the 1743H.

2. Low Temperature Cathode - An M type dispenser cathode of identical design to the present type B cathode used in the 120 CGB gun will be used. No electrical or mechanical design changes are necessary. The type M cathode will provide the required cathode emission current density of 2.3 A/cm^2 at a minimum of $50^{o}C$ lower operating temperature. Hughes is currently using a type M cathode on the production 605H TWT with an operating temperature higher than the proposed tube.

3. PPM Focusing - Samarium cobalt magnets will replace the existing Alnico stack to provide the required PPM focusing field. No change in the basic PPM parameters ($B_z o$, $\lambda p/L$) is planned. The higher energy product of the Sm Co_5 magnets will provide more available axial field with a reduced magnet OD, thus reducing weight. This design has already been developed for the 595H S-band TWT.

4. RF Circuit - The basic RF circuit design of the 1743H will be used. The Hughes patented reentrant loss and tapered termination techniques will be incorporated into the output section to reduce amplitude and phase variations from the regenerative effects of the specified maximum load VSWR. These techniques are currently used in all the coupled cavity communications TWTs as well as in the 595H S-band radar tube.

These proposed design improvements (except for the M cathode) have been developed in the 1743H, and 595H S-band TWTs. Test results from these programs will provide the necessary data to further refine the designs for application into the 1757H. The marriage of the latest technology advances with the pioneer design of the 1743H should produce a very reliable TWT for the TPQ-37.

The details of the proposed tube design are presented in the following sections.

3.2 ELECTRON GUN

The electron gun for the proposed tube will be identical in mechanical and electrical design to the 120 CGB gun developed for use on the 1743H. A description of this gun is given in Section 2.0. This gun was developed and tested as part of a reliability improvement program.

In order to obtain longer operating life and decrease susceptibility to grid shorts and grid emission, an improved cathode material will be utilized which will permit operation at a minimum of $50^{\circ}C$ lower temperature.

The present electron gun used on the 1743H tubes has a type B tungsten matrix dispenser cathode. This cathode operates around 1100°C to provide space charge limited emission at a cathode current density of 2.3 A/cm^2 Figure 3-1 shows that for the type B cathode at 1100°C, the zero field current density is 3.2 amperes per square centimeter. The space charge current density is always lower than the zero field current density because the current must be limited by the geometry and not by the temperature.

Figure 3-2 gives predicted average cathode life for 10 percent current degradation as a function of temperature. This equates to a life of 10,000 hours for a type B cathode operation at 1100°C.

In order to improve the life and reliability of the TWT, Hughes proposes to incorporate a type M dispenser cathode of identical dimensions in place of the type B cathode. A Type M cathode is basically a type B cathode that has been coated or doped with osmium to lower the work function. Type M cathodes have been shown to work effectively in TWTs at more than 50°C lower temperature while at the same cathode current loading. The reduced operating temperature provides two advantages to the tube operation:

1. An increase in cathode life of up to four times the present type B cathode. Figure 3-1 indicates that at 3.2 amperes per square centimeter of zero field current density the operating temperature of the Type M cathode could be as low as 990°C or 110°C below the B type cathode. At this low temperature, Figure 3-2 shows a cathode life of 40,000 hours for the Type M cathode or four times the predicted life of the Type B cathode.

2. A reduction in barium evaporation rate. Barium coming off the cathode accumulates on the shadow and control grid vanes increasing the probability of grid arcs. Barium also condenses on the inside surfaces of the ceramic insulators causing increased leakage current. The rate of barium evaporation is reduced

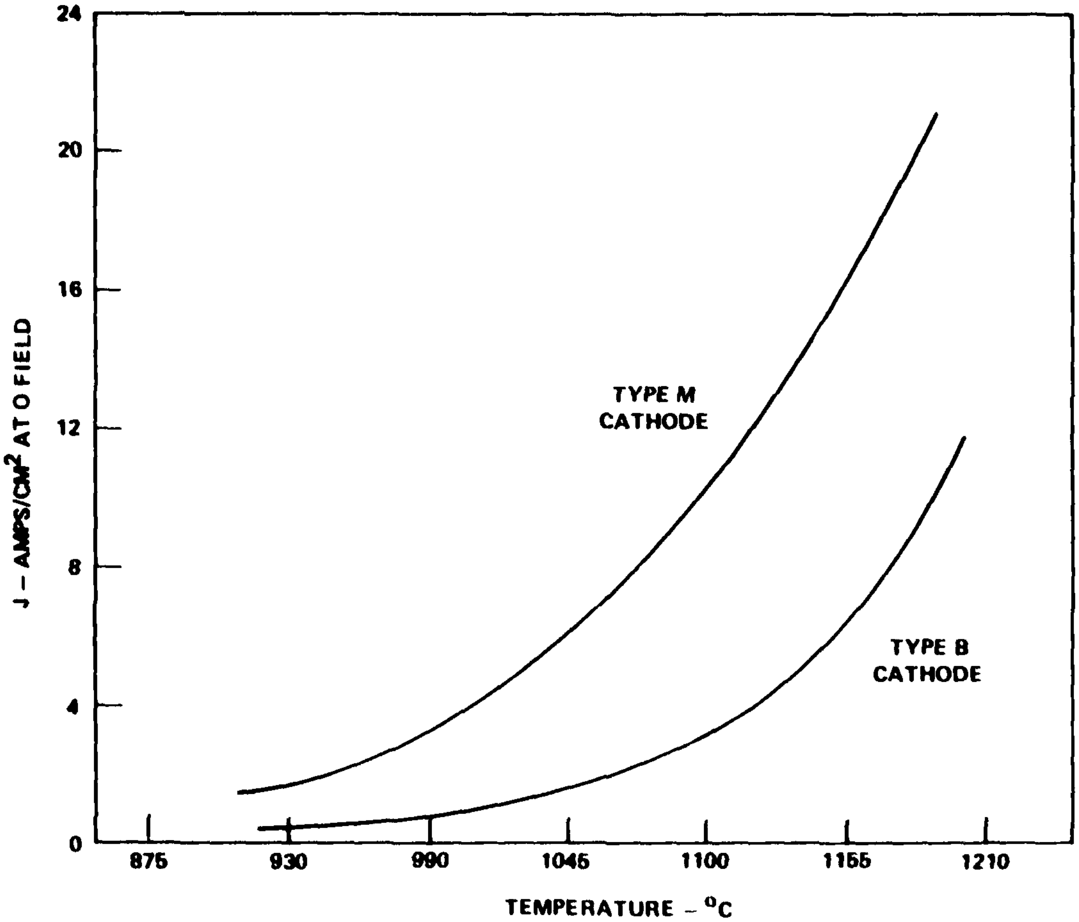

Figure 3-1 Emission as a function of temperature for type M and type B cathodes.

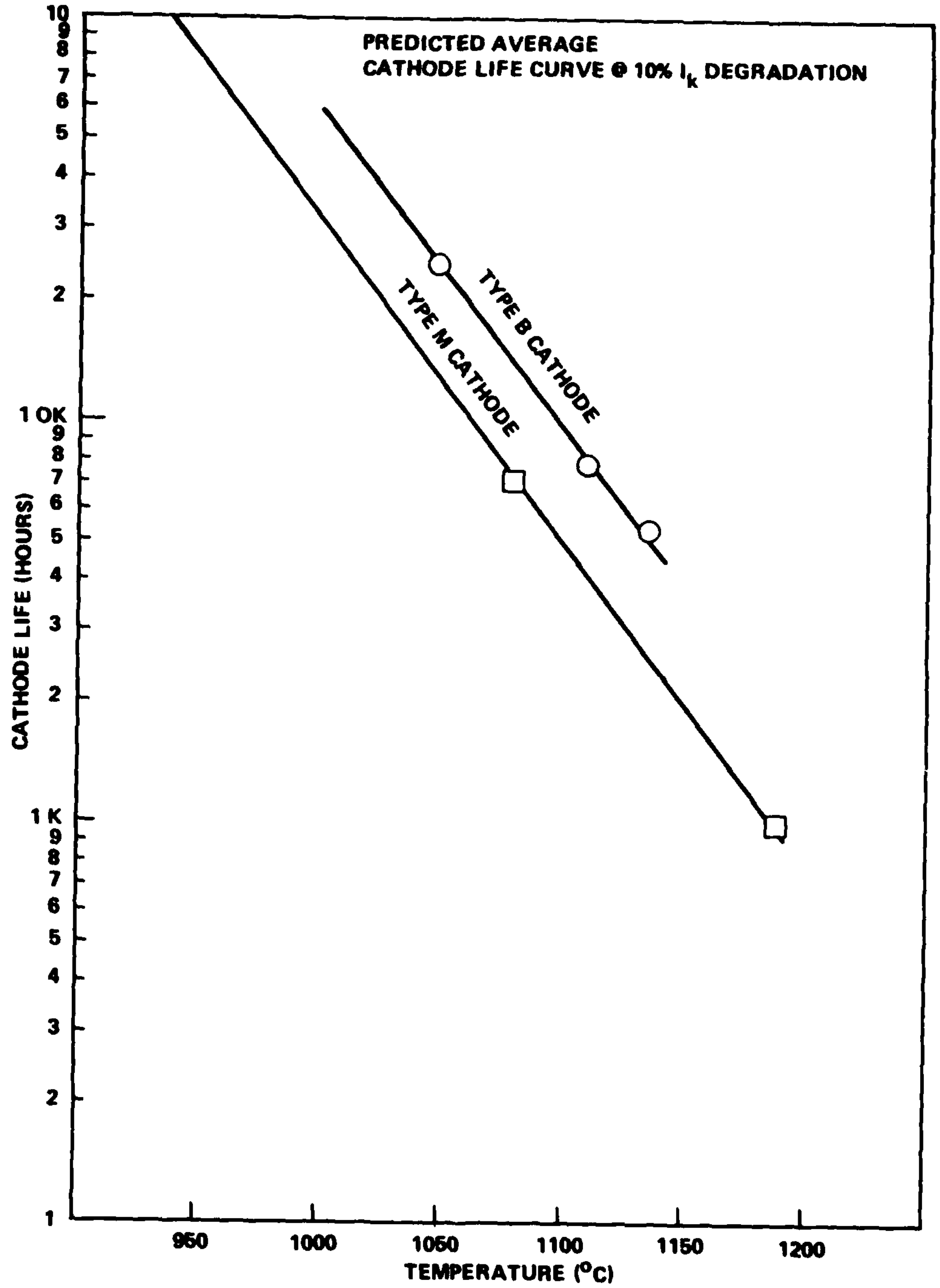

Figure 3-2 Cathode life as a function of cathode temperature.

one half for every 30°C reduction in cathode temperature. Thus the temperature differences of over 90°C between the type M and B cathode, as shown in Figure 3-1, would reduce the barium evaporation by 87 percent.

The incorporation of the M type cathode requires no mechanical or electrical design changes to the 120 CGB isolated anode gun. This approach totally avoids having to reoptimize entrance conditions and possibly degrade beam transmission. Hughes plans to test the first isolated anode electron gun in a triode. The triode will be identical to the TWT except there will be no RF interaction circuit. The triode will be processed and tested just like a TWT. In this way, the electron gun can be completely evaluated before the TWT is built. In addition, one cathode from each lot that is received will be fired in a vacuum chamber to verify the mechanical integrity of the Osmium-Ruthenium overcoat. The building and testing of the triode is shown as a milestone in the program schedule.

3.3 RF CIRCUIT

The present RF coupled cavity circuit design used in the 1743H meets all the requirements of the specification with a matched load.

In order to meet the specified performance into the worst case system mismatch, a Hughes patented technique will be implemented into the basic 1715H circuit to reduce regenerative effects. This technique is used in all Hughes communications TWTs to provide very flat amplitude and phase performance in the small signal region. In addition the technique has already been developed at S-band for the 595H TWT.

Gain and phase variations with frequency are caused by feedback which is due to miltiple reflections set up by mismatches in the discontinuity regions of a traveling wave tube. The main discontinuties occur in the waveguide-to-circuit transitions, the internal terminations which isolate the individual sections, and the system load. Since the distance between mismatches is electrically long, the phase of the feedback alternates rapidly with frequency from positive to negative, thus causing regeneration and degeneration. Maximum regeneration occurs when the phase shift of a wave traveling around the feedback loop is an integral multiple of 2π. Thus, successive maxima in gain occur when the electrical length of the feedback loop changes by one wavelength. The magnitude of the gain variations depends upon the forward gain, backward loss, and the mismatches. In theory, if perfect matches and no backward wave interactions could be achieved, there would be no gain variations. In practice, however, only less than perfect matches can be achieved and backward waves do propagate within the cavities.

Hughes has developed several methods of improving gain variations by reducing the mismatches associated with the discontinuity regions and increasing the backward loss of the circuit. The internal terminations normally used in coupled-cavity circuits are of relatively short electrical length, being confined to a single cavity. As a result the mismatch of these terminations can only be reduced to a low but imperfect level. Hughes has developed and and patented a tapered internal termination for coupled-cavity circuits that extends over several cavities. The long electrical length of this termination and the gradually tapering loss pattern results in a very low mismatch. This technique also introduces in-band loss in the section, further reducing the feedback effect. The tapered loss is obtained by using small cavities adjacent to the circuit cavity; these cavities are loaded with lossy ceramic "buttons" that protrude significantly into the cavity. The protrusion or re-entrancy of a button determines the amount of in-band loss, with the more re-entrant buttons providing more loss. The amount of loss is easily tapered in successive cavities by simply changing the amount of button re-entrancy. The tapered termination is illustrated in Figure 3-3.

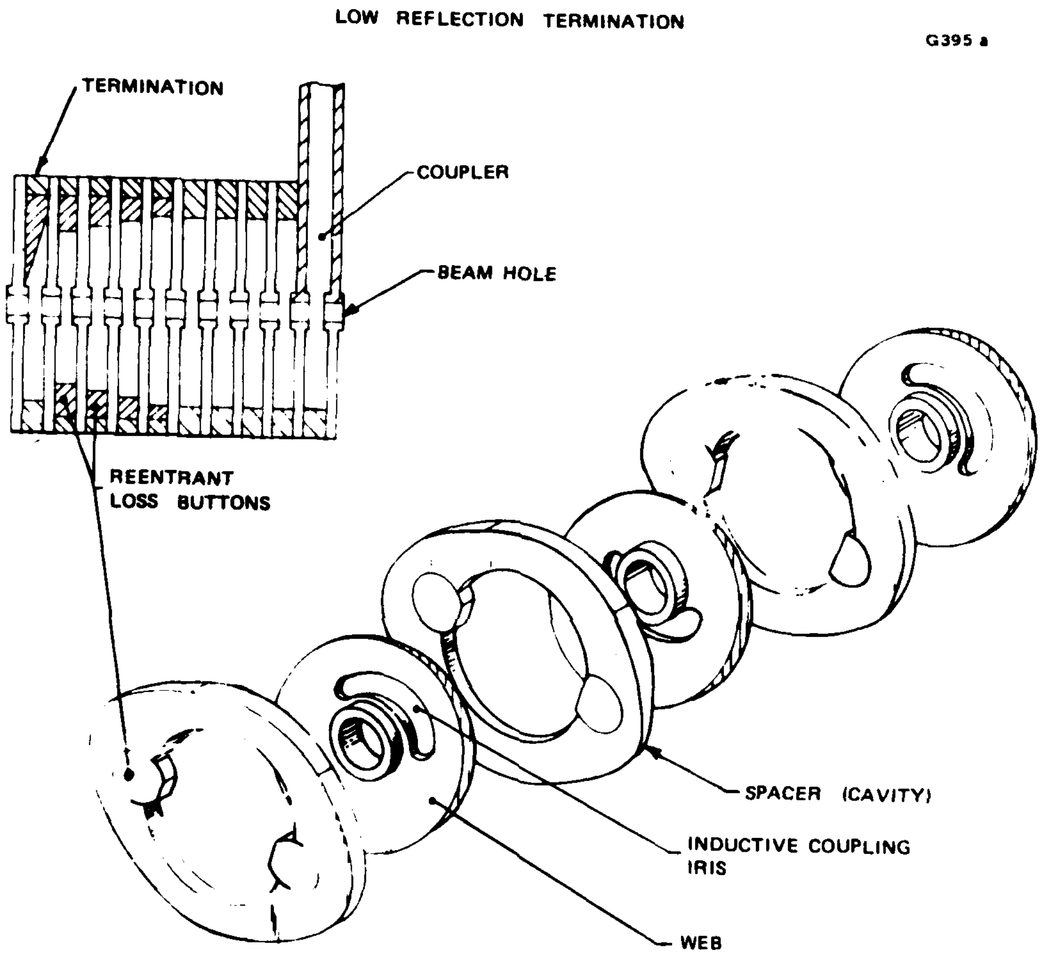

Figure 3-3 Coupled cavity slow-wave circuit.

The incorporation of this technique has little or no effect on the efficiency and average power capability of the tube. The gain in the output section is carefully adjusted to achieve maximum efficiency (about 28 dB) without excess gain which degrades linearity. Since the loss is positioned at the input end of the output section where the RF fields are low, no significant RF heating takes place. Reentrant loss has been used in X-band tubes at power levels as high as 14 kW CW.

The design and test of the reentrant loss and tapered termination for the S-band PPM focused 595H TWT has been completed. A typical cavity assembly clearly showing the buttons is shown in Figure 3-4. The affect of inband loss to reduce gain variations and to reduce the feedback caused by external mismathces is dramatic. Figure 3-5 is a power output versus frequency plot with a constant input RF drive level. The TWT is operating into a 1.5:1 VSWR that is varied through all phases. The maximum variation in power output is seen to be only 0.7 dB. Without inband loss, the power variations would be on the order of 2 dB. There is no doubt that inband loss will improve both the performance and the reliability of the 1757H.

3.4 PPM FOCUSING

Excellent focusing, with and without RF drive, is achieved on the 1743H providing high efficiency and low circuit operating temperatures. Presently a double period Alnico VIII design is used. Split ring magnets, 4 inches in diameter, extending completely around the circuit circumference and two cavity periods long provide the approximately 1000 gauss axial focusing field. With the double period focusing design every other circuit pole piece is inside the magnet ID.

To reduce the size and weight of the proposed tube, the Alnico magnets will be replaced with smaller samarium cobalt magnets. This design has already been developed for use on the 595H 250 kW S-band TWT and is shown

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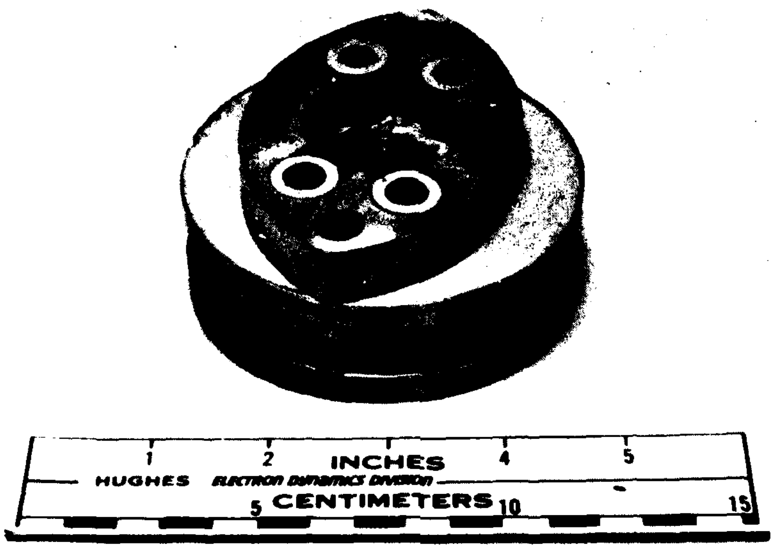


Figure 3-4 Reentrant loss section for the 595H TWT.

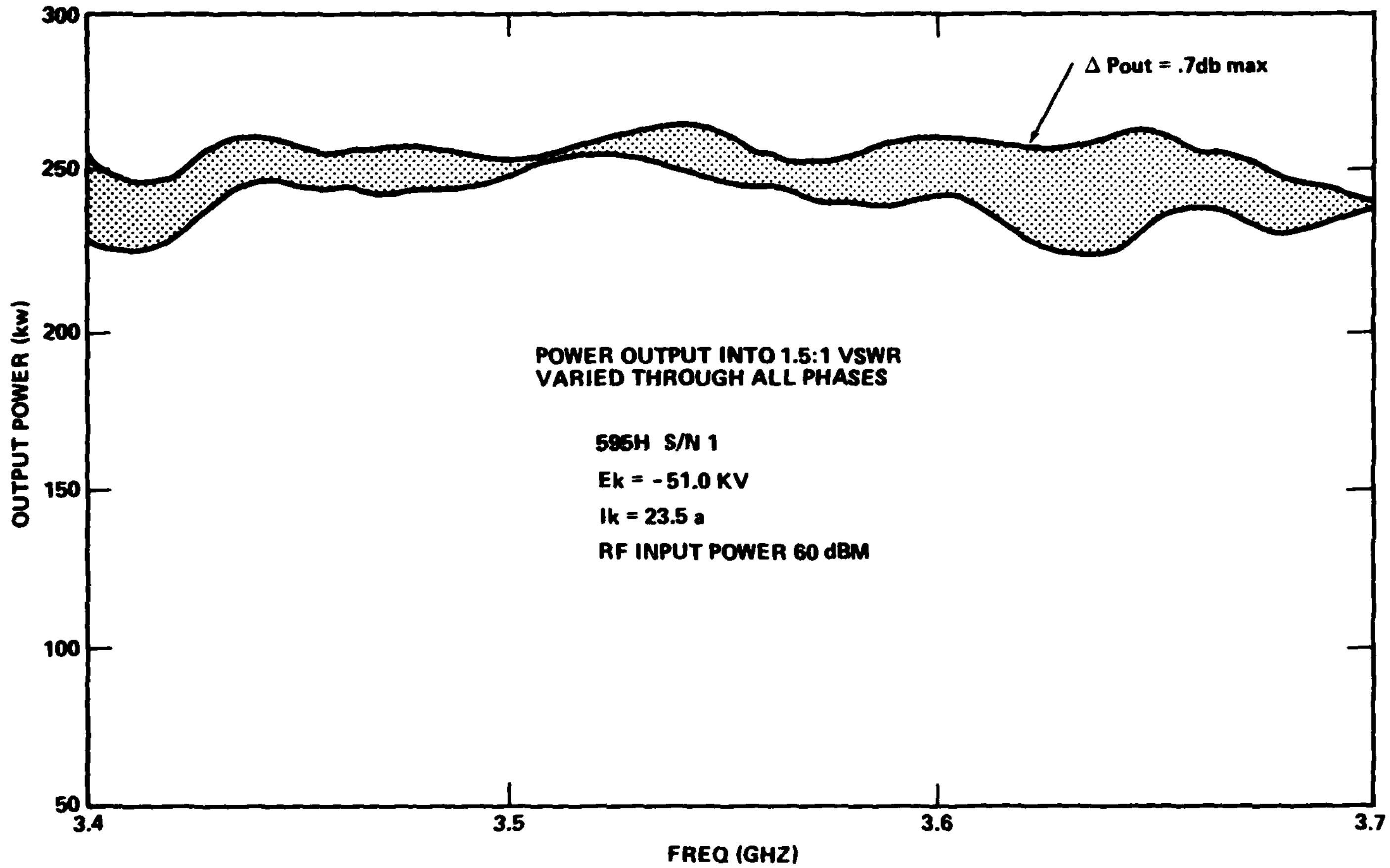


Figure 3-5 *Effect of mismatch on power output.*

in Figure 3-6. Four small rectangular magnets are used between every circuit pole piece to provide the same 1000 gauss on axis. The direction of magnetization is alternated every cavity period to provide the same field as the double period Alnico stack.

The circuit pole piece diameter is reduced to 3.6 inches for an estimated 40 pound weight savings per tube. The use of 4 magnet segments every cavity period rather than 2 half rings every two cavity periods will allow greater optimization of the magnetic field. Thus the focusing should be improved.

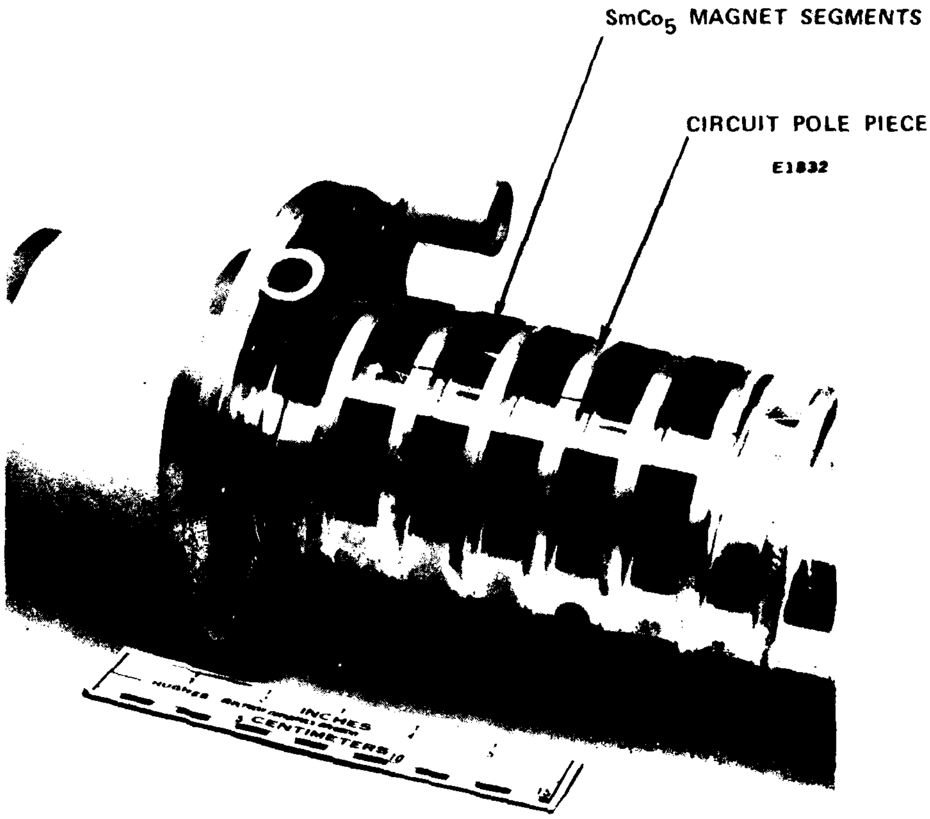


Figure 3-6 Samarium cobalt PPM focusing stack.

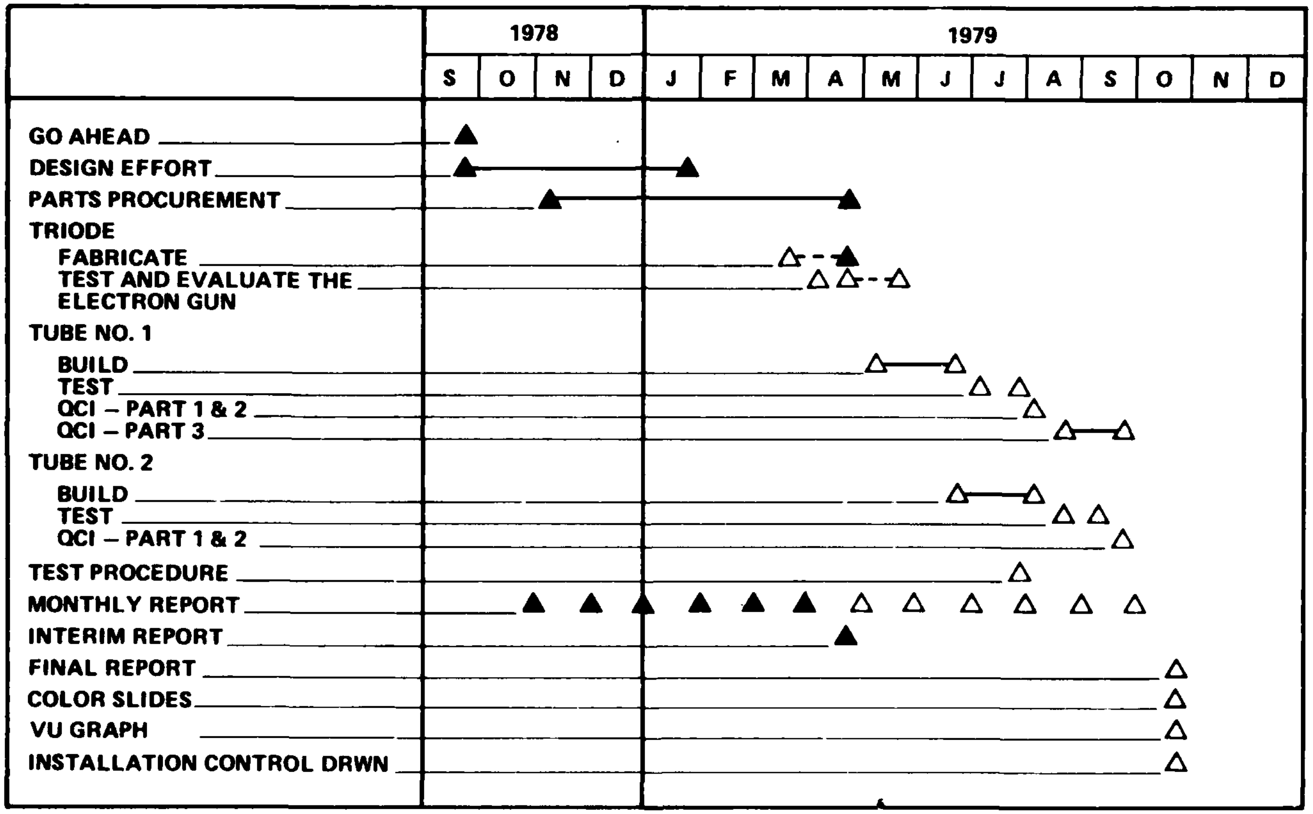
4.0 STATUS

At the end of the interim period, the engineering effort and documentation have been completed. Piece part procurement was essentially done and subassembly fabrication has begun. The build of the electron gun has been delayed approximately one month because of damaged cathodes that were rejected as receive from the vendor. The electron gun fabrication was completed at the end of April as indicated in the milestone schedule.

5.0 SUMMARY

The program has proceeded without significant problems, except for the damaged cathodes which had to be replaced. The improvements to be incorporated are not unique in that they have been accomplished on similar programs. Hughes feels confident in the technical implementation of these improvements and in the result to be achieved.

1757H TWT PROGRAM SCHEDULE



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